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OVERVIEW OF THE FAA ADS-B LINK DECISION

Summary

This paper presents an overview of the FAA decision on the ADS-B link architecture for use in the National Airspace System and discusses the associated operational implications.

Additional documentation is available from the FAA web site in a background paper titled: "The approach and Basis for the FAA ADS-B Link Decision" available from the FAA web site at: www.faa.gov/asd

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INTRODUCTION

- **RTCA has defined Automatic Dependent Surveillance-Broadcast (ADS-B) as:**
  "ADS-B is a function on an aircraft or surface vehicle that periodically broadcasts its state vector and other information."
- **History of ADS-B leading to a link decision**
  - The basic concept of ADS-B traces its origins back to at least the early 1970s. The earliest of the three candidate ADS-B link technologies currently being considered has its origins in the late 1980s.
    - The candidate link technology with the longest history is Very High Frequency Digital Link (VDL) Mode 4 (VDL-M4) which traces is origins back to the very late 1980's with developments in Sweden.
    - The second candidate ADS-B link technology is 1090 MHz Extended Squitter, which was developed in the early 1990s and builds upon Mode Select (Mode S) radar standards and technology.
    - The third candidate ADS-B link technology is the Universal Access Transceiver (UAT), which was developed starting in the mid-1990s.
  - The FAA has continued to conduct research into the capabilities of the specific ADS-B links since the first tests in 1992 and research activities have continued until the present.
  - In 1993 RTCA Task Force 2 recommended that a Special Committee be established to develop standards for ADS-B. This lead to the creation of RTCA Special Committee 186 in 1994. SC-186 published the ADS-B MASPS in 1998.
  - In 1995 RTCA Task Force 3 identified ADS-B as an enabling technology for 'Free Flight'.
  - In the late 1990's the FAA established the Safe Fight 21 program as a joint government/industry initiative designed to demonstrate and validate, in a real-world environment, the capabilities of advanced surveillance systems and air traffic procedures associated with free flight, using Automatic Dependent Surveillance - Broadcast (ADS-B) and Traffic Information Services - Broadcast (TIS-B) as enabling technologies.
  - The FAA working with RTCA formed the ADS-B Link Evaluation Team (LET) in December 1998. This later evolved into the FAA/EUROCONTROL co-chaired Technical Link Assessment Team (TLAT). The focus of the TLAT was on assessing the technical performance of the three individual candidate ADS-B links. The TLAT issued their final report in March 2001.
  - The FAA and Eurocontrol have participated in cooperative activities for the testing and simulation of the three candidate ADS-B links.
  - The FAA has sponsored additional post-TLAT testing and simulation activities to address specific technical issues that were raised by the TLAT.
  - The FAA sponsored 3 public meetings during 2001 to solicit economic data from avionics manufactures and airspace users, which was then used by the FAA in an Cost Benefit Analysis comparing various ADS-B single link and multi-link alternatives.

MOTIVATION TO IMPLEMENT ADS-B

- Increase Safety
  - Improve visual acquisition especially for general aviation flight under Visual Flight Rules (VFR) (using air-to-air in the near term supplemented by Traffic Information Service-Broadcast [TIS-B] in the mid-term)
  - Reduce runway incursions on the airport surface through improved aircraft surface situational awareness (including use of TIS-B from a multi-lateration surveillance source) (mid-term)
  - Provide graphical weather to general aviation cockpit (Flight Information Services-Broadcast, i.e., FIS-B) (mid-term)
- Increase capacity and efficiency of National Airspace System (NAS) operations
  - Enhanced visual approaches (air-to-air) (near-term)
  - Closely spaced parallels (air-to-air and air-to-ground) (mid-term)
  - Reduced spacing on final approach (air-to-air) (near-term)
  - Reduced aircraft separations (mid-term)
  - Enhanced operations(1) in high altitude airspace for the incremental evolution in the direction of the "Free Flight" concept (air-to-air and air-to-ground) (long-term)
  - Surface operations in lower visibility conditions (mid or long-term)
  - Near Visual Meteorological Conditions (VMC) capacities throughout the NAS in most/all weather conditions (long-term)
  - Support improved ATC services in non-radar airspace
- Strategy for Equipage: Stimulate voluntary equipage by enabling benefits for all user/aircraft classes
  - General Aviation: Cockpit display of traffic and flight information (TIS-B and FIS-B)
  - Air Carrier: Beneficial applications in the terminal environment and on the airport surface

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Note (1): In 1995 RTCA Task Force 3 defined the "Free Flight" concept and identified a number of potential beneficial operations that could be enabled or enhanced by providing Cockpit Display of Traffic Information (CDTI) to the pilot and by providing airborne decision support tools. ADS-B was identified as an enabling technology for providing such enhanced airborne capabilities. The FAA will work with the airspace users to progress the definition, validation and the incremental implementation of such enhanced capabilities.

TIME FRAME DEFINITIONS

- Near-Term (2002-2006):
  - Defined as the period prior to deployment of ADS-B national ground infrastructure
  - Some "pockets" of ground infrastructure may exist or may be deployed (1)
  - Principal efficiency benefits are expected to be pairwise air-to-air in the terminal environment, except in "pockets" where additional benefits are possible
  - Air carrier and general aviation begin to equip
- Mid-Term (2007-2012):
  - Defined as the period during which the ADS-B national ground infrastructure will be deployed
  - Benefits grow from increased pairwise opportunities as the commercial aircraft fleet completes ADS-B equipage
  - Initial enroute ADS-B enabled applications are identified, validated and implemented
  - NAS Ground Infrastructure will be deployed from 2007 through 2012 to provide ADS-B air-to-ground surveillance services and ground-to-air uplink broadcast services over 1090 MHz Extended Squitter (1090ES) and Universal Access Transceiver (UAT)(2)
    - ADS-B surveillance data (i.e., call sign, position, velocity, intent, etc.) will provide improved ATC surveillance for controllers
    - Ground will uplink TIS-B where the ground infrastructure is deployed
      - Pilots of aircraft equipped for ADS-B reception and CDTI will have common situational awareness with the ATC controller
      - TIS-B can also provide the same situational awareness to the pilot as provided to ATC for airport surface operations where multi-lateration services exist(3)
    - Ground uplinks FIS-B (only via UAT) where the ground infrastructure is deployed
      - Pilots of aircraft equipped with UAT and a suitable cockpit display can receive graphical weather services for improved safety
  - Requirements for longer-range air-to-air (>40 nmi.) applications may be validated for operation in the long-term
- Long-Term (Post-2012):
  - Air carrier fleets achieve the intended initial ADS-B benefits in the terminal and enroute airspace
    - Terminal and enroute ADS-B enabled applications continue to be defined, validated and implemented
  - GA fleet continues to equip with ADS-B to receive TIS-B and FIS-B services throughout the NAS

Notes: (1) Current pockets of ground infrastructure include Safe Flight 21 and Capstone locations (i.e., Ohio Valley and Alaska)

(2) The current NAS architecture calls for ADS-B ground infrastructure at all long range secondary radar locations and at 150 major terminals thus providing air-ground coverage similar to the NAS coverage of the current secondary radars. Some gap filler ADS-B ground stations will be deployed in non-radar locations.

(3) ADSE-X systems are planned to include support for ADS-B and TIS-B.

LINK DECISION SUMMARY

- To satisfy short range (≤40 nmi.) air-to-air applications and longer range (up to 200 nmi.) air-to-ground ATC surveillance applications in the NAS
- Two ADS-B technologies are selected for use in the NAS: 1090ES and UAT
  - Aircraft that fly in high altitude airspace would equip with 1090ES
  - General Aviation aircraft that are not capable of high altitude operations would equip with UAT
  - Interoperability between the links will be provided within coverage of the ground ADS-B infrastructure using the multilink gateway service provided via the TIS-B uplink (ground-to-air)(1)
  - TIS-B is also used to provide "ADS-B reports" on aircraft that are not transmitting ADS-B information (this is especially useful during the equipage transition period)
- 1090ES is selected for the airspace that is principally used by the domestic and international commercial aircraft.
  - ICAO SARPs and RTCA MOPS [i.e., DO-260] exist for 1090ES, however avionics conformant to the forthcoming second version of the 1090ES MOPS [i.e., DO-260A] will be required. It is anticipated that DO-260A will be published by RTCA by mid-2003.
  - FAA is coordinating with Eurocontrol for the selection of 1090ES as the interoperable link for the U.S. and the core of Europe
  - 1090ES is expected to provide 40 nmi. air-to-air range in the high density and high interference environments and 90 nmi. in the low density and low interference environments as per the current ADS-B MASPS(2)
  - Within coverage of the ground infrastructure, TIS-B on the 1090MHz uplink will provide reports for non-ADS-B equipped aircraft and a multilink gateway service, as a companion service to TIS-B, will provide ADS-B reports for UAT equipped aircraft

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Notes: (1) Interoperability – Because of the approach proposed, the air carrier aircraft will equip with 1090ES and the general aviation aircraft will equip with UAT. Therefore interoperability between links is of concern where the air carrier and the general aviation aircraft will operate in the same airspace, namely in the major terminal environment. In this airspace interoperability is not a major issue because of the positive control nature of the terminal environment (namely ADS-B is principally used to enhance efficiency and not see-and-avoid operations).

(2) The ADS-B MASPS requirements can be satisfied in the near and mid-term by 1090ES. Further studies will be required to determine at what traffic density and interference levels the range requirements cannot be satisfied with 1090ES alone.

LINK DECISION SUMMARY (Continued)

- UAT is selected to provide ADS-B and associated services for the general aviation users because of its lower cost and greater uplink capacity, especially for FIS-B services.
  - 978 MHz selected as the UAT frequency for the U.S. Stage 3 spectrum approval from NTIA was granted January 2002. Stage 4 approval is expected by mid-2002.
  - UAT avionics must be conformant to the forthcoming UAT RTCA MOPS, the first version of which is expected to be published by RTCA in late 2002
  - U.S. supports progressing UAT ICAO SARPs so that UAT can be considered an international candidate for ADS-B
    - U.S. implementation of UAT for GA does not require SARPs
    - If long range air-to-air applications are validated for use in the long-term that cannot be satisfied by 1090ES alone, UAT would be a leading candidate to support these requirements
  - Within coverage of the ground infrastructure TIS-B on the UAT uplink will provide reports for non-ADS-B equipped aircraft and a multilink gateway service will provide ADS-B reports for 1090ES equipped aircraft
- U.S. will work with ICAO and partners around the globe to establish the ADS-B link(s) for global interoperability
  - The FAA will propose 1090ES as the initial global ADS-B link
    - 1090ES is expected to provide good enough range performance (i.e., $\geq$ 40 nmi. for at least a decade.
  - If it is determined that 1090ES cannot meet the long term needs in terms of capacity or desired range, the FAA will participate with the ICAO community to select a suitable long-term ADS-B link.

EXPECTED EQUIPAGE

- Air Carriers, including international, and other aircraft that will fly in high altitude enroute airspace are expected to equip, as a minimum, with 1090ES for ADS-B and TIS-B services
- General Aviation are expected to equip with UAT for ADS-B, TIS-B and FIS-B services with 40% to 70% equipage estimated in the long-term
- Commuter airlines, and perhaps some high-end GA, that fly in high altitude airspace used by commercial aviation and that also fly into non-radar airports (where UAT is the predominate ADS-B link and TIS-B cannot be provided) may elect to equip with UAT in addition to 1090ES

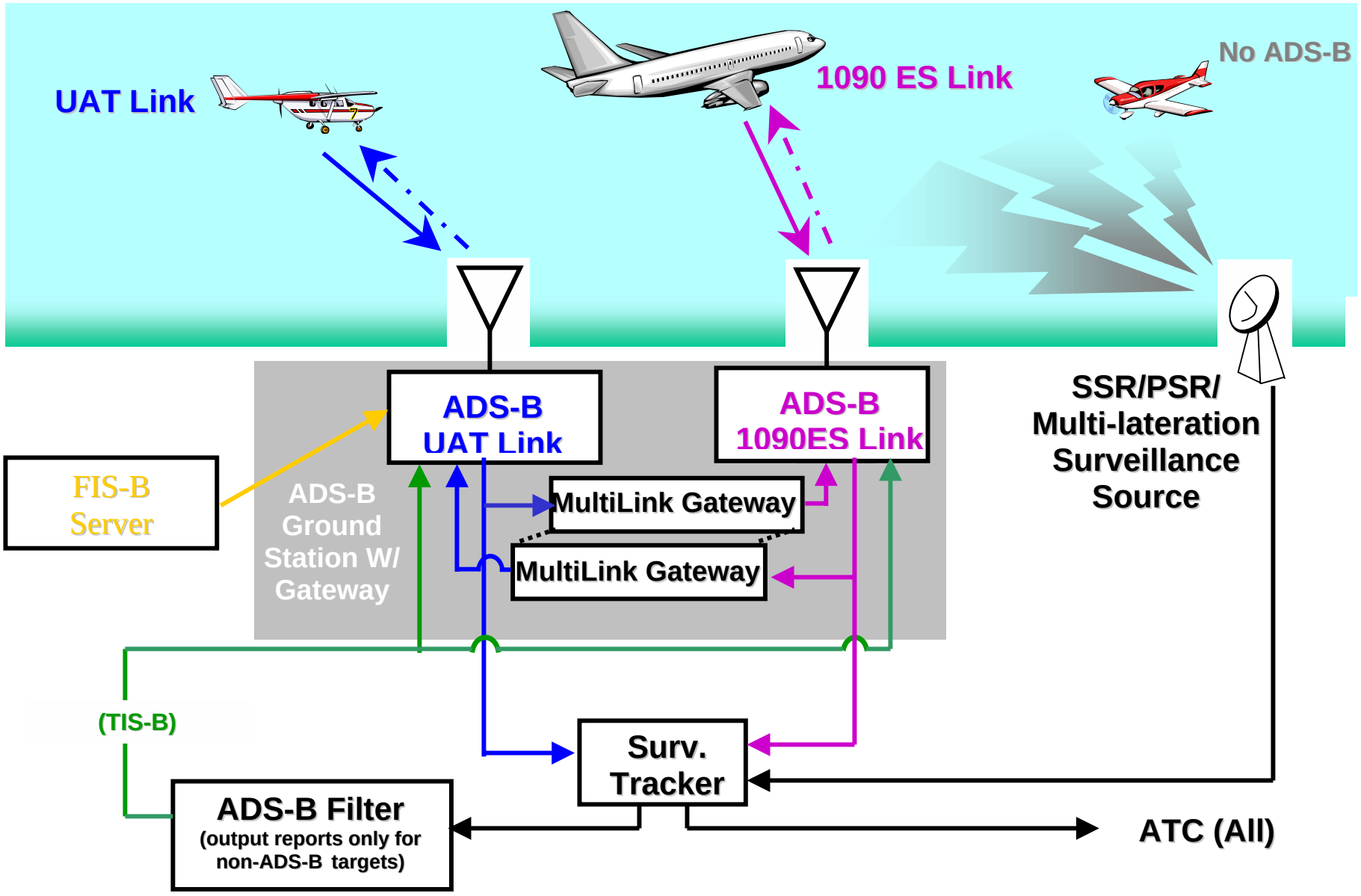
TIS-B – NEEDED FOR COMPLETE SITUATIONAL AWARENESSE

- TIS-B supplements ADS-B air-to-air services to provide complete situational awareness in the cockpit of all traffic known to the ATC system
- TIS-B is an important service for an ADS-B link in airspace where not all aircraft are transmitting ADS-B information (e.g., call sign, position, velocity, etc.)
- The ground ADS-B station transmits surveillance target information on the ADS-B data link for each aircraft in that airspace that is not transmitting ADS-B information on that same link (i.e., for unequipped aircraft or aircraft transmitting only on another ADS-B link)
  - Complete TIS-B service can only be provided in airspace where the ground has surveillance of all aircraft in the airspace via primary/secondary radar, multi-lateration and/or ADS-B from another link
  - The update rate and accuracy of TIS-B uplinks is largely determined by the characteristics (i.e., accuracy, update rate, etc.) of the best available ground surveillance data source
    - ground radars for primary and secondary targets
    - multi-lateration systems for targets on the airport surface or within the immediate surrounding terminal airspace
    - ADS-B systems for targets equipped with a different ADS-B link

MULTILINK GATEWAY SERVICE – FOR ACHIEVEING INTEROPERATIBLITY IN LOW ALTITUDE AIRSPACE

- The ground multilink gateway service will be implemented as a companion to TIS-B within the same ground ADS-B station hardware platform
- The ground ADS-B stations relay ADS-B information received from one ADS-B equipped aircraft to all other aircraft that are only equipped with a different ADS-B link technology
  - ADS-B ground stations use ground-to-air broadcasts to relay the ADS-B information
  - for targets transmitting ADS-B information on a specific ADS-B link, the update rate and the accuracy of the ADS-B multilink gateway service will to a large extent be determined by the characteristics of the ADS-B link used by that aircraft target
  - some small additional latency in the reception of target aircraft updates will be introduced by use of the ground multilink gateway as compared to direct air-to-air reception of ADS-B

Functional Architecture for ADS-B Ground Station
(Including FIS-B, TIS-B and MultiLink Gateway Functions)



OPERATIONS IN HIGH ALTITUDE ENROUTE AIRSPACE

- Anticipated End-State Operation: all aircraft are transmitting ADS-B (call sign, position, velocity, intent, etc.) on 1090ES
- ATC System is receiving and using high accuracy, high update rate surveillance from 1090ES ADS-B link
- Aircraft (predominately domestic and international air carriers) that are receiving and displaying ADS-B data will see all aircraft on 1090ES
- Although TIS-B would be provided over 1090 MHz, this service is generally not necessary in the high altitude enroute airspace after full 1090ES transmit equipage is achieved
- During the mid-term, requirements may be validated for longer-range (i.e., >40 nmi.) air-to-air applications for use in high interference, high altitude airspace that 1090ES alone cannot satisfy. If 1090ES is shown to not support the needed range, then a second ADS-B link (e.g., UAT or VDL-Mode 4) would be needed to support these longer-range air-to-air requirements. Avionics and airframe manufacturers should consider how this additional link capability could be accommodated at acceptable costs.

OPERATIONS IN HIGH DENSITY TERMINAL AND TRANSITION AIRSPACE

- Anticipated End-State Operations: most aircraft in such airspace are transmitting ADS-B data on 1090ES or UAT links
- Aircraft equipped with ADS-B reception and display capability will:
  - see all aircraft transmitting ADS-B data on own ADS-B link, via air-to-air link
  - see all aircraft transmitting ADS-B data on the other ADS-B link, via ADS-B multilink ground gateway service
  - be authorized to participate in ADS-B enabled applications
- Aircraft not equipped with ADS-B reception and display capability will be excluded from ADS-B enabled applications
- FIS-B services will be provided on UAT
- ATC system is using high accuracy, high update rate surveillance from 1090ES and UAT ADS-B links

OPERATIONS IN LOW DENSITY RADAR AIRSPACE

- ATC surveillance uses a combination primary/secondary radar and ADS-B reports
- Some aircraft are transmitting ADS-B information on 1090ES, some on UAT, and some are not equipped with ADS-B at all
- Aircraft equipped to display ADS-B target aircraft information will receive:
  - ADS-B directly from other aircraft transmitting on the same ADS-B link
  - target reports via the ADS-B multilink gateway service for aircraft equipped with the other ADS-B link
  - lower quality target reports via TIS-B for other aircraft not equipped with ADS-B
- UAT equipped aircraft would receive flight information services via FIS-B including graphical weather
- ATC surveillance is derived from both primary/secondary radar and ADS-B

OPERATIONS IN LOW DENSITY/REMOTE NON-RADAR AIRSPACE

- ATC surveillance provided by ADS-B
  - Improved ATC services may be available for ADS-B equipped aircraft
- FIS-B services may be provided on UAT
- Airspace users are predominately general aviation and commuter/air taxi
- General aviation aircraft are transmitting ADS-B information on UAT, commuter/air taxi aircraft transmitting on 1090ES and/or UAT, air carriers (if any) are transmitting on 1090ES and many aircraft are not equipped with ADS-B at all
- Aircraft equipped to display ADS-B target aircraft information will receive ADS-B directly from other aircraft transmitting on the same ADS-B link
  - only an incomplete situational awareness would be possible because TIS-B is not available
  - multilink gateway services would provide interoperability among the ADS-B equipped users
- If a multi-lateration system were also implemented, TIS-B could be provided on the airport surface and in the immediate terminal airspace, including at pattern altitude.

OPERATIONS IN AIRSPACE WITHOUT GROUND SURVEILLANCE INFRASTRUCTURE

- No ADS-B equipage would be required such airspace
- No radar or ADS-B enabled ATC services supported
- No TIS-B or FIS-B services provided
- GA aircraft are transmitting ADS-B information on UAT, commuter/air taxi aircraft transmitting on 1090ES and/or UAT, and many aircraft are not equipped with ADS-B at all
- Aircraft equipped to display ADS-B target aircraft information will receive ADS-B directly from other aircraft transmitting on the same ADS-B link
  - only an incomplete situational awareness would be possible

IMPLICATIONS TO THE AVIONICS INDUSTRY

- The near and mid-term baseline avionics configurations are expected to be:
  - 1090ES ADS-B conformant to second version of the 1090ES RTCA MOPS [i.e., DO-260A] for air carriers
  - UAT ADS-B conformant to the first version of the UAT RTCA MOPS for general aviation
  - Dual suite 1090ES and UAT for special cases (e.g., commuter aircraft that operates in both high altitude enroute airspace and also flies into airports where there are predominately general aviation users)

- In the long-term 1090ES or UAT transmit-only capability may be desired
  - To satisfy anticipated needs for ATC services
    - UAT transmit-only capability alonge would not satisfy the required equipage for aircraft that operate in high altitude enroute airspace
  - For aircraft desiring to receive improved ATC services in non-radar environments (e.g., Capstone – Alaska)

- Avionics manufactures are encourage to provide a flexible avionics architecture to accommodate dual link equipage in the long term
  - Air carrier avionics architecture for 1090ES with an option for UAT
    - In the near and mid-term some 1090ES equipped air carriers may desire to also equip with UAT receivers in order to receive FIS-B and/or to directly see UAT-only equipped target aircraft in the case where the ground multilink gateway service is unavailable.
    - UAT might become a necessary second link in the long-term in order to receive the full benefits of ADS-B if long range air-to-air applications are validated and the requirements cannot be satisfied by 1090ES
  - Corporate and commuter avionics architecture should support both 1090ES and UAT
  - A GA avionics architecture that supports 1090ES in addition to UAT may be appropriate for those users that desire to also equip with a Mode S transponder capability

- **DEFINITIONS**

ADS-B Automatic Dependent Surveillance-Broadcast provides the periodic broadcast of an aircraft's position, velocity, identity and other information

CBA Cost-Benefit Analysis

CDTI Cockpit Display of Traffic Information is a generic display that provides the flight crew with surveillance information about other aircraft, including their position. Traffic information for a CDTI may be obtained from one or multiple sources (including ADS-B and TIS-B).

FIS-B Flight Information Service-Broadcast provides the ground-to-air uplink of weather graphics and text. FIS-B could use the UAT ADS-B link.

Multilink Gateway A function of an ADS-B ground station that is used to provide interoperability between different ADS-B link technologies by receiving ADS-B reports via Link A and broadcasting the target information via Link B and vice versa.

TIS-B Traffic Information Service-Broadcast is a ground-to-air broadcast of target reports based on surveillance information available on the ground. Generally primary/secondary radar surveillance information will be available and at some airports multi-lateration data will be available. The TIS-B service may also provide a multilink gateway service (see above). TIS-B would use the ADS-B link.

1090ES 1090 MHz. Extended Squitter is an ADS-B link technology based on Mode S technology.

UAT Universal Access Transceiver is an ADS-B link technology that would operate at 978 MHz.

VDL-Mode 4 Very High Frequency Digital Link-Mode 4 is an ADS-B link technology that would operate on multiple 25 KHz. channels in the VHF radio navigation band.

VMC Visual Meteorological Condition